MESOSCALE CLOUD STATE ESTIMATION FROM VISIBLE AND INFRARED SATELLITE RADIANCES

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in collaboration with

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OUTLINE

- Motivation and problem statement
- Analysis of information content of satellite remote sensing measurements in the cloud state estimation
- 4DVAR research algorithm
- 4DVAR data assimilation experiments
- Conclusions

WHY MESOSCALE CLOUD STATE ESTIMATION?

- High resolution atmospheric state analysis under all weather conditions
- More accurate analysis of other environmental conditions dependent on weather
- Weather forecast initialization and verification

Mesoscale weather analyses currently imply regional domains

Motivation similar for global systems

EXCERPT FROM

Recent developments at ECMWF

by M. Miller :

Obvious importance of clouds and precipitation

Satellite data represent 95% of the data ingested into the ECMWF analysis system, but most of the satellite radiances (about 75 %) are not used because they are diagnosed as cloud- or rain-affected

Assimilation of moist variables into NWPs challenging due to the wide range of spatial and temporal scales

State-of-the-art global NWP models describe cloud and precipitation with a reasonable degree of realism

MESOSCALE CLOUD STATE ESTIMATION PROBLEM

Cloud state definition

3D spatially distributed cloud hydrometeors with microphysical properties

Approach to resolution

- Assimilation of cloud sensitive remote sensing measurements on mesoscales into a cloud resolving forecast model

Methodology

- 4D assimilation techniques
- Research data assimilation algorithm to test information content of remote sensing observations of clouds in 4D
- Diagnostic studies of error characteristics specific to the cloud estimation

CLOUD AND PRECIPITATION SENSITIVE REMOTE SENSING

Satellite

regional to global coverage

resolution approaching mesoscales

Radar

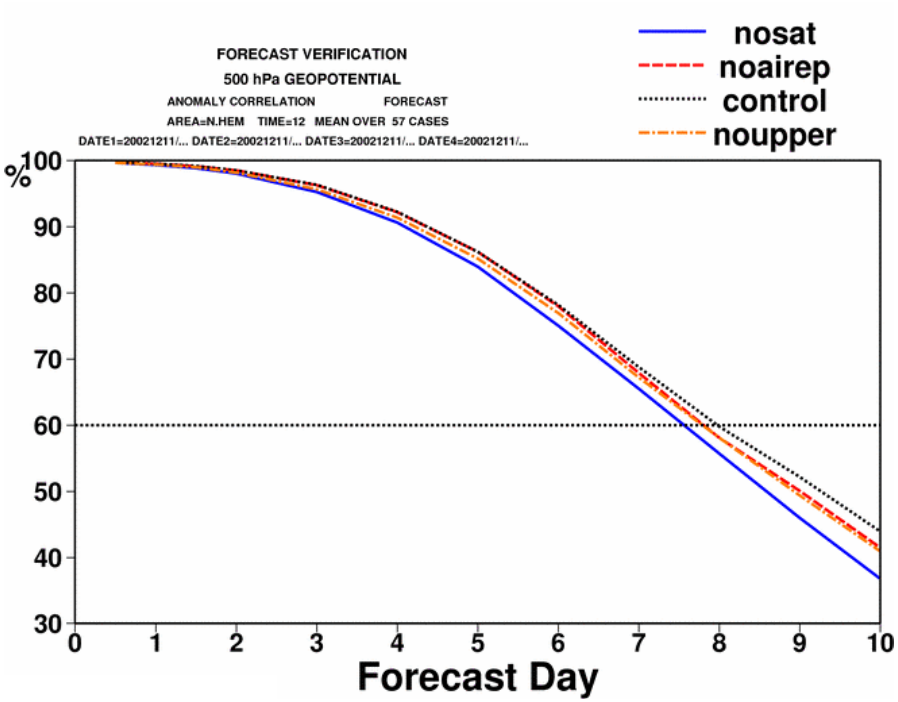
selected regional coverage

high resolution

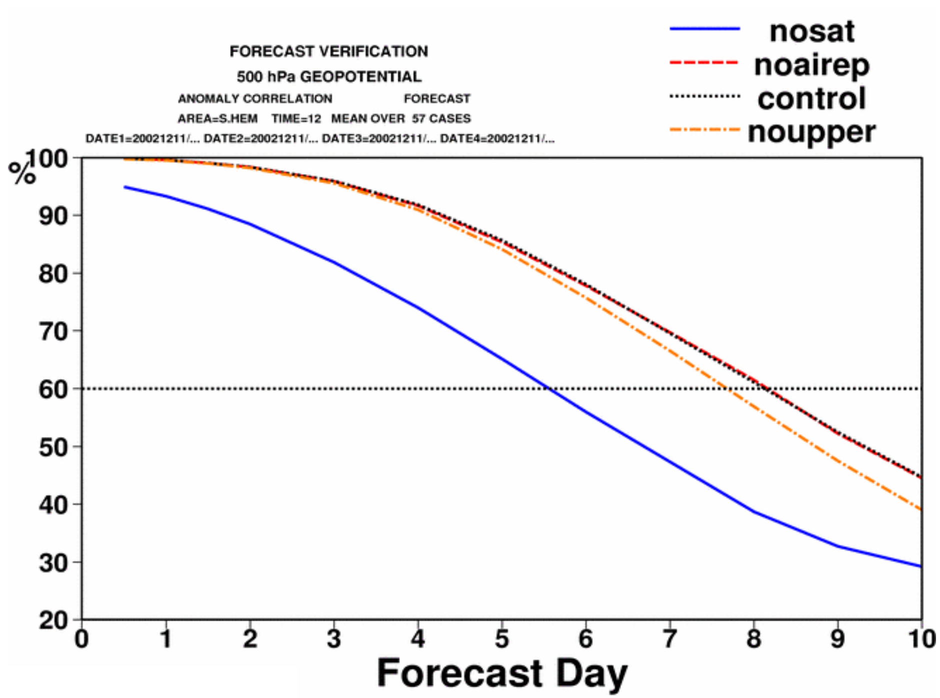
Example from global scale systems / from Miller (ECMWF)

New Observing-System Experiments

Northern hemisphere



Southern hemisphere



Verification against control analysis

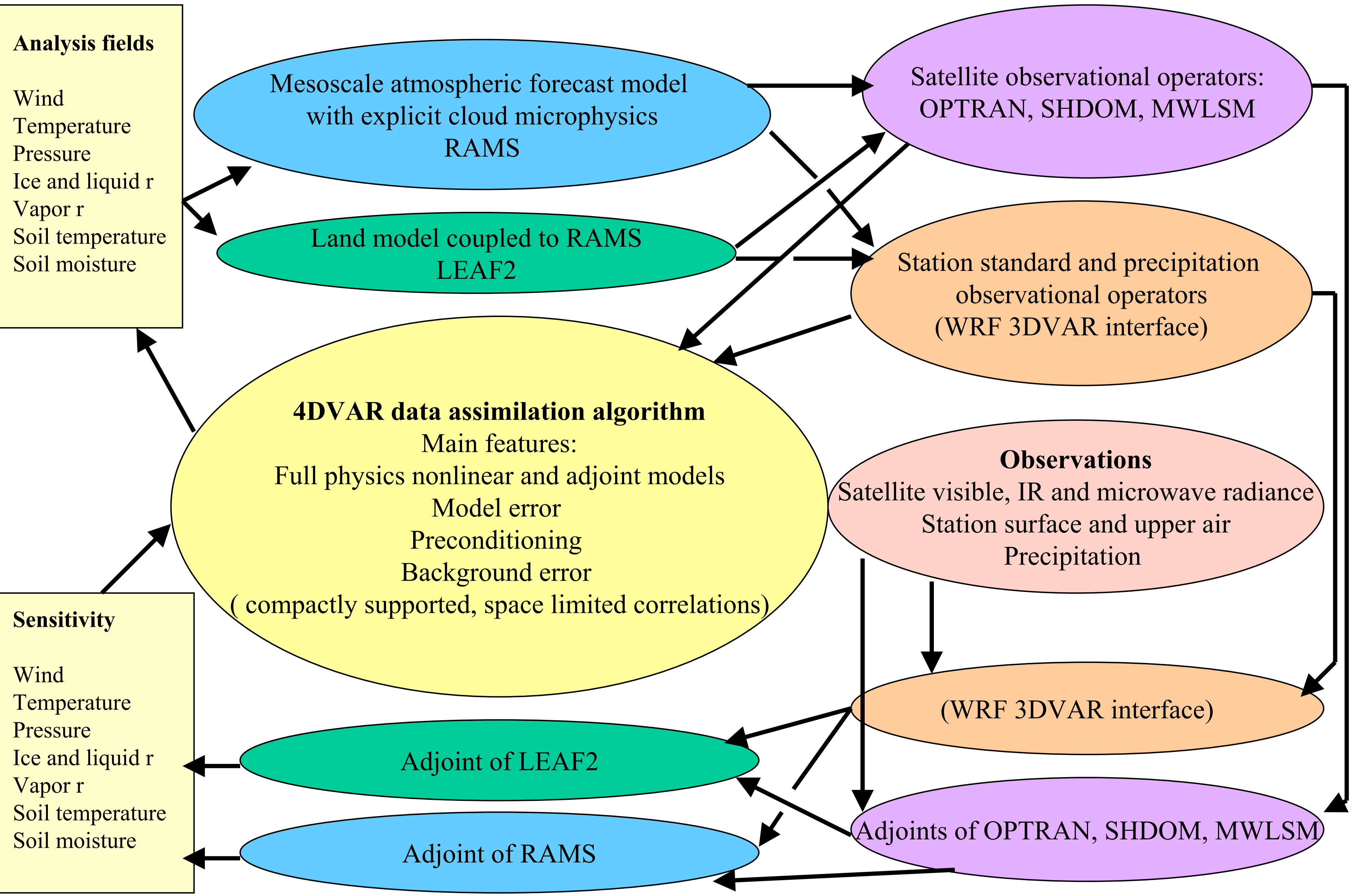
Our research on cloud state estimation from satellite remote sensing

Start

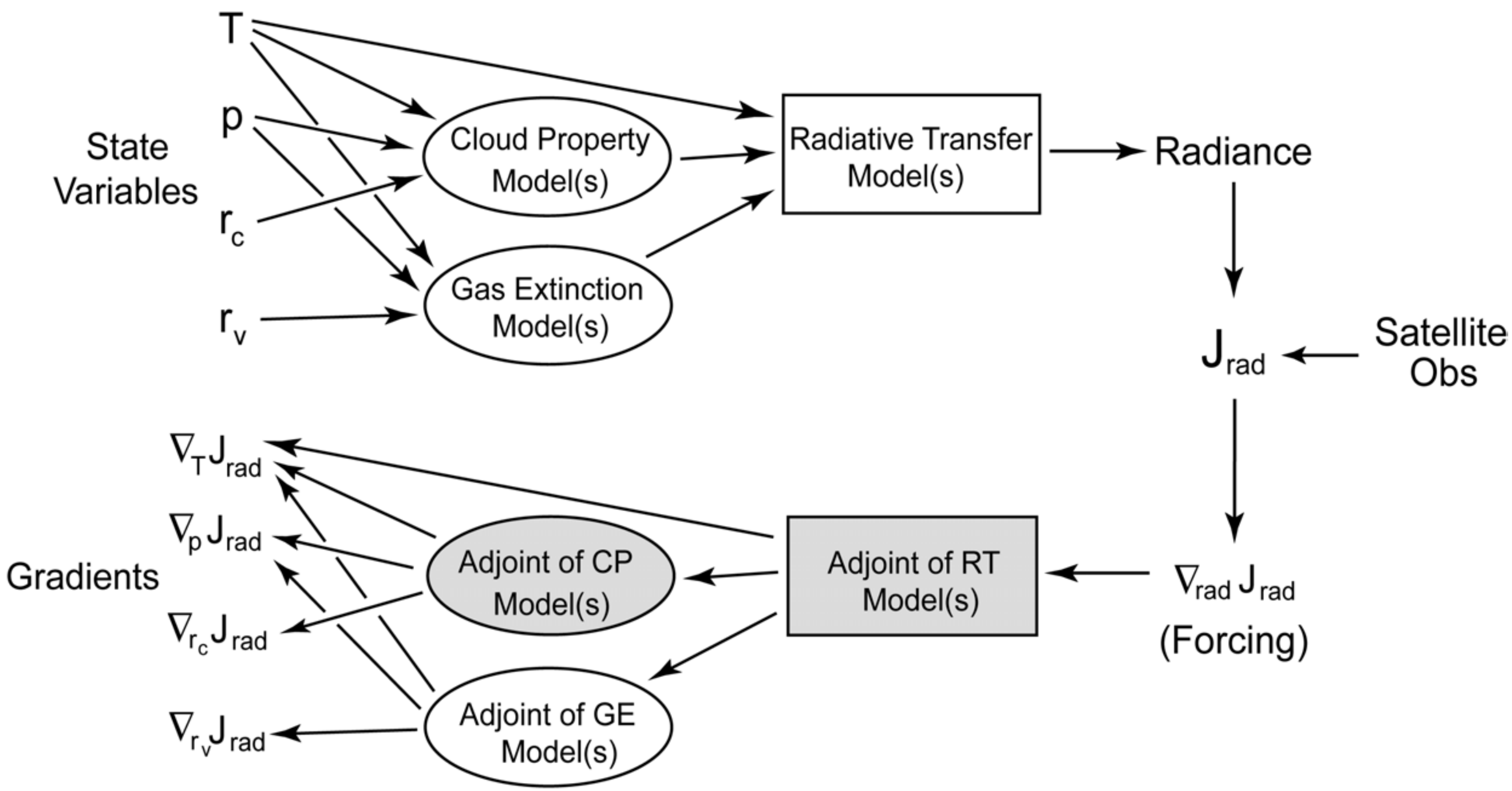
- Observations: VIS and IR GOES imager radiances
- Mesoscale forecast model: CSU Regional Atmospheric Modeling System (RAMS) with explicit cloud prediction (7 types of hydrometeors)
- Assimilation method: Nonlinear least square estimation solved by 4D variational technique (4DVAR)

Regional Atmospheric Modeling and Data Assimilation System
RAMDAS

Arrows show direction of data flow



VIS and IR observational operator



4DVAR DATA ASSIMILATION EXPERIMENTS

Case: PBL continental stratus in Southern US,
May 2 1996

Model configuration:

- 51 levels variable vertical grid
- 25 km horizontal grid span up by 5 km nested
- forecast
- liquid cloud microphysics

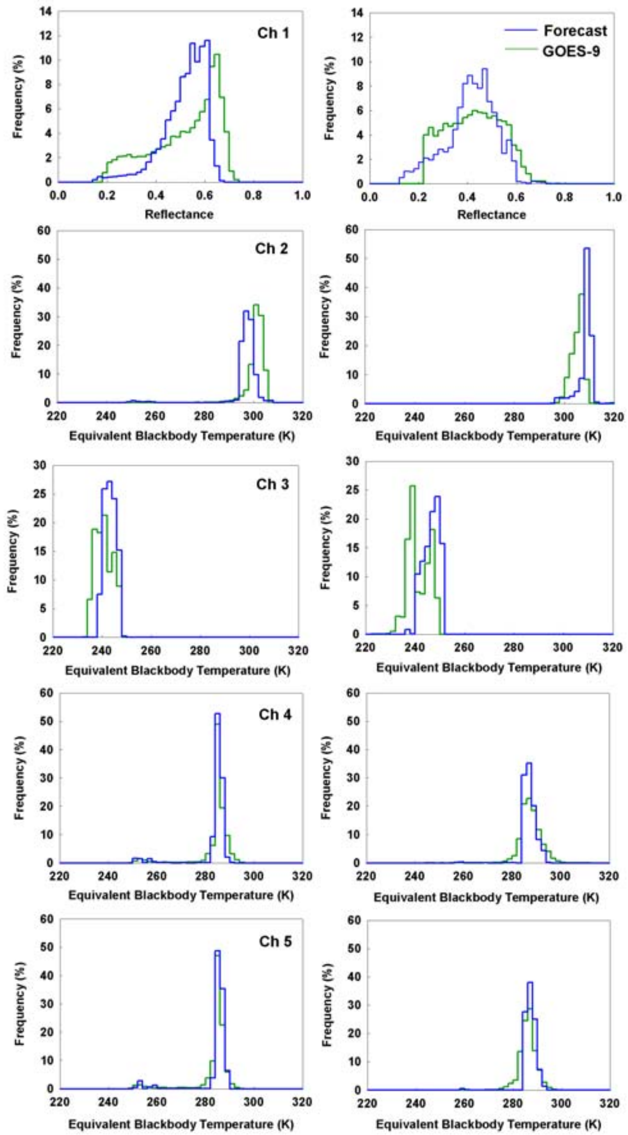
Experiments:

1. 1 grid box observations: VIS and IR GOES imager
2. All IR 10.7 μm measurements over low level cloud region

Cloud forecast verification in GOES imager space

liquid continental stratus

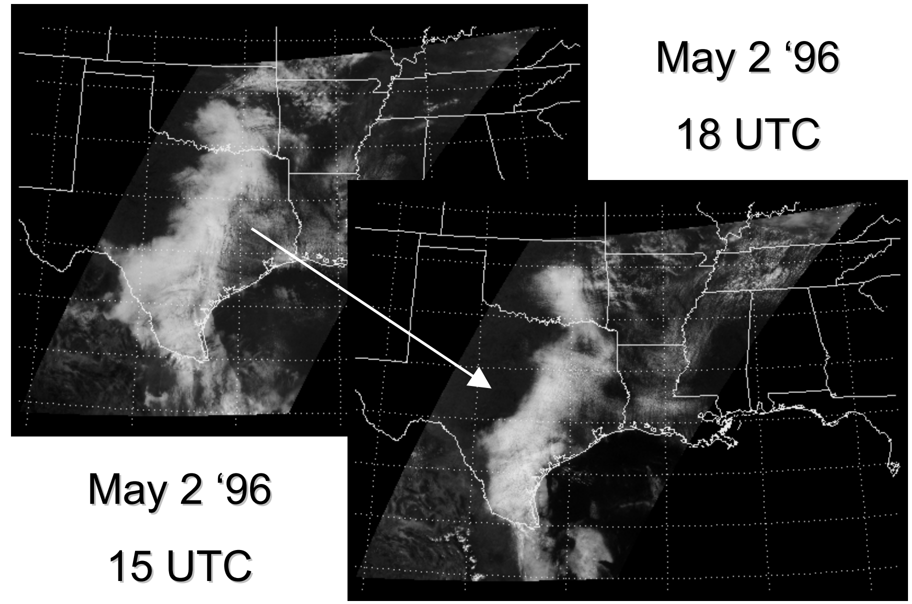
15 h 18 h



Visible

Near-IR

IR



May 2 ‘96

18 UTC

May 2 ‘96

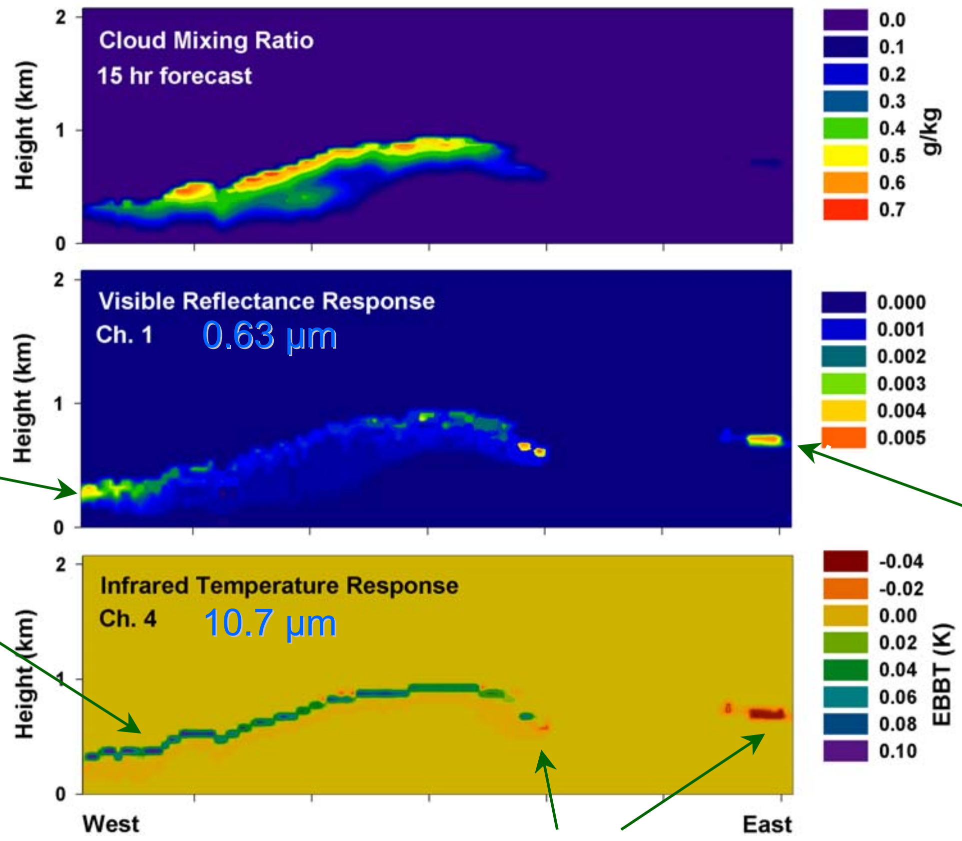
15 UTC

Key result

Simulated cloudy radiances capture observed temporal/spatial changes

VIS and IR information content analysis: sensitivity of measurement to cloud mixing ratio

Liquid stratus case



Cloud forecast mixing ratio

Visible

IR

Positive sensitivity near cloud top

Sensitivity greatest for thinnest clouds

Negative sensitivity for thin clouds

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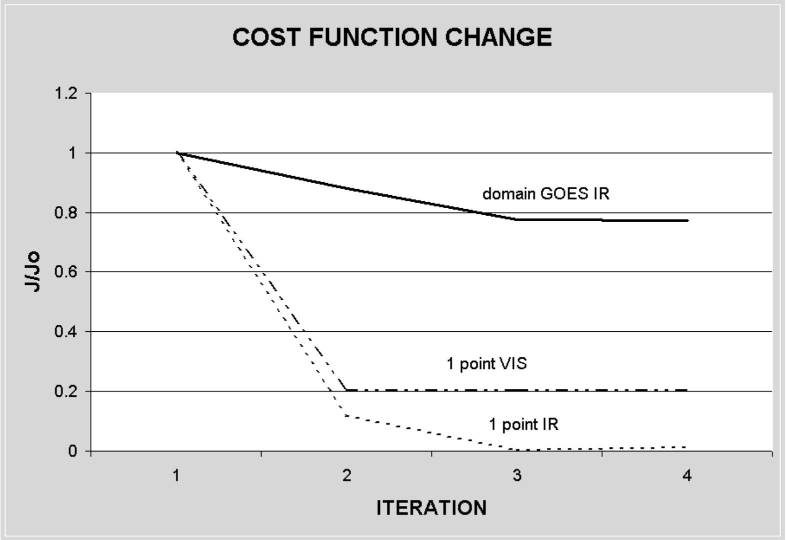
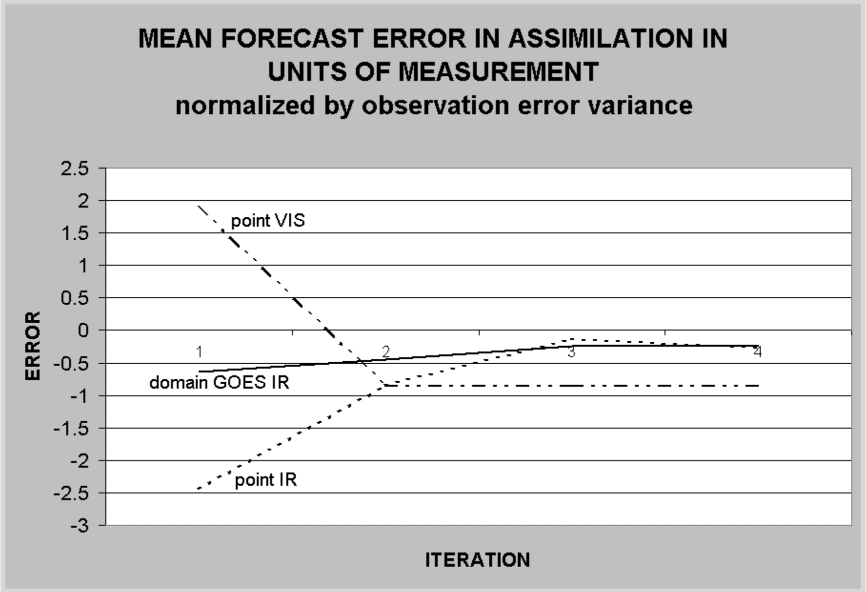
Summary of VIS and IR assimilation results

Assumed error variances: 1.0 for Tb and 0.1 for reflectance





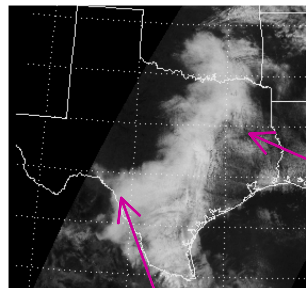
Key result: Assimilation converged successfully to small mean forecast error in the cloud domain

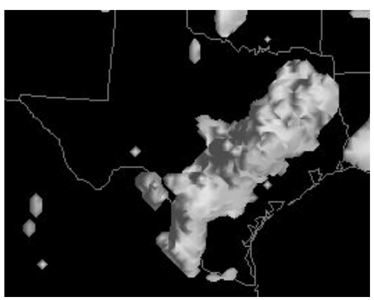
Impact of GOES IR 10.7µm on cloud in assimilation

Key result

Cloud cover and Tb improved

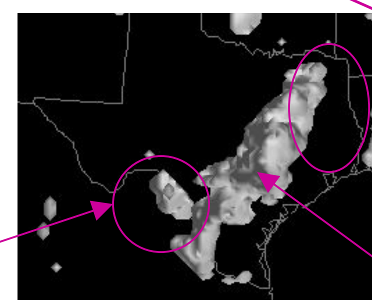
Observed cloud VIS image





cloud before assimilation

enhanced



reduced

cloud after assimilation

thickened

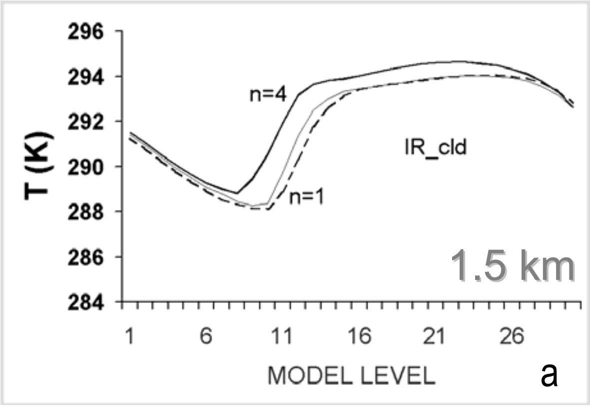
What happened in 3D?

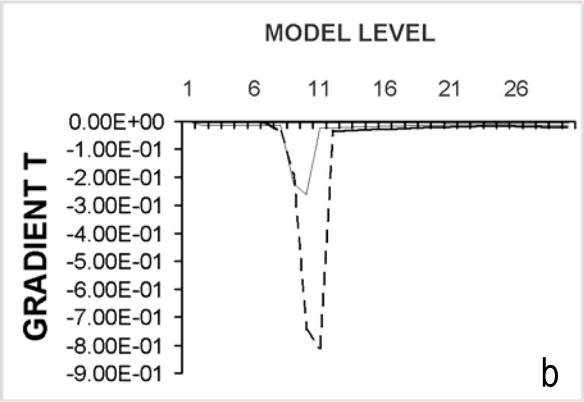
Vertical response at a location with negative cloud cover error

Warming and drying

in inversion layer

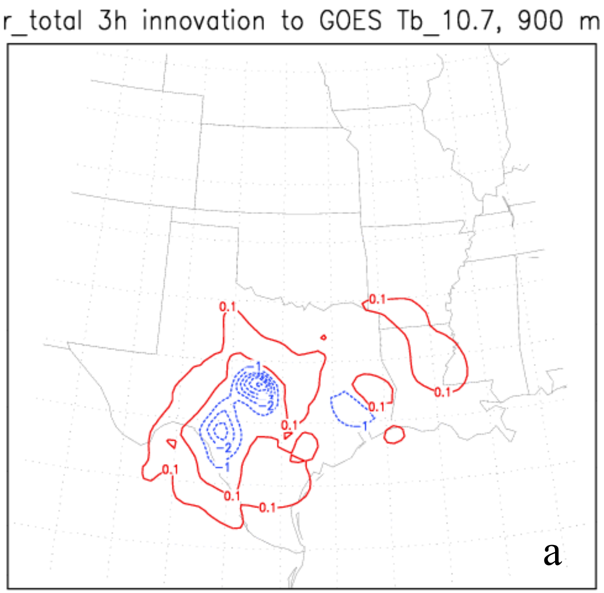
Sensitivity of cost function diminishes as cloud is removed



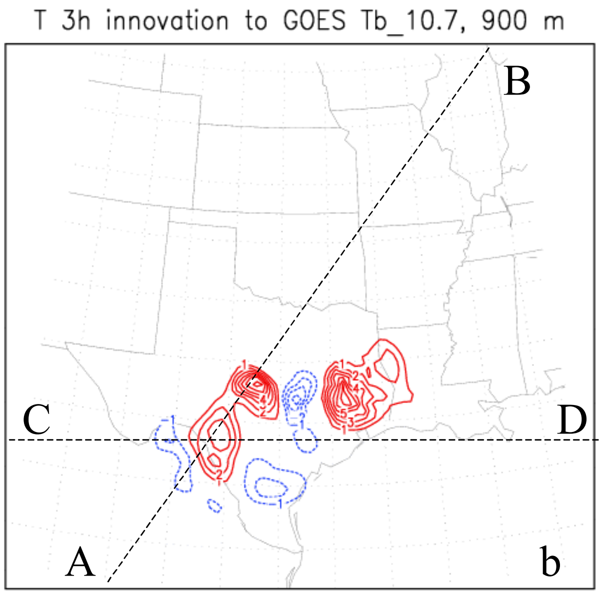


What happened in 3D?

Horizontal response within a layer near the cloud top



Total water mixing ratio



Potential temperature

Key result

Cloud is enhanced/diminished where there is cooling/heating associated with moistening/drying

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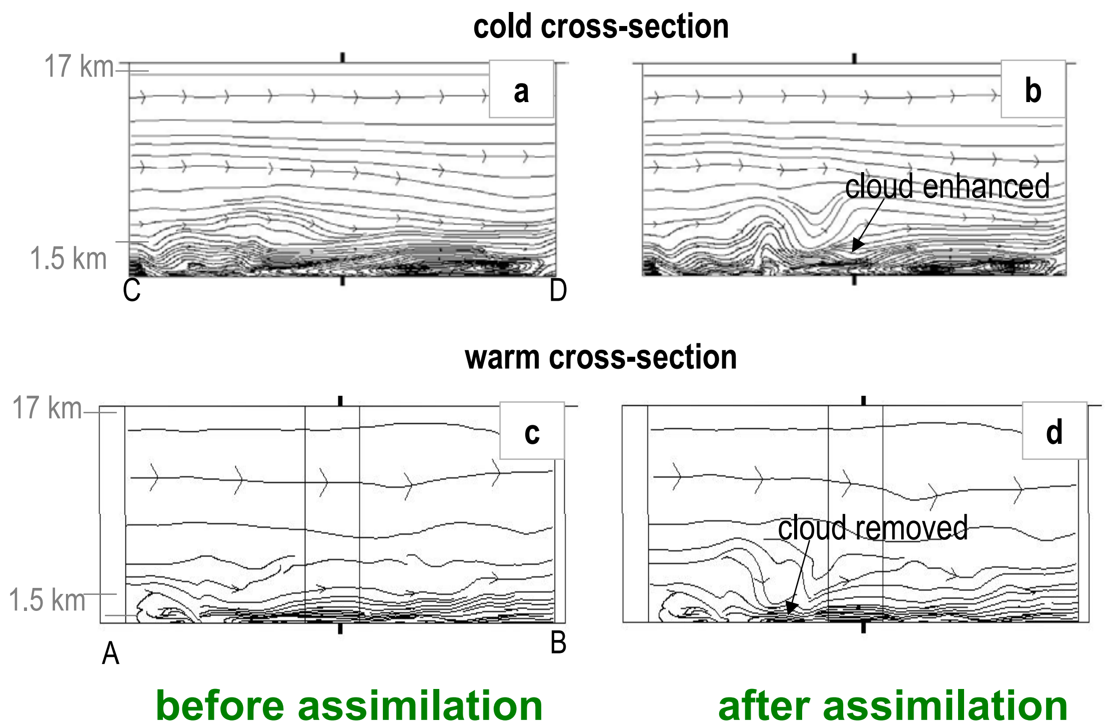
What happened in 3D?

Dynamical response

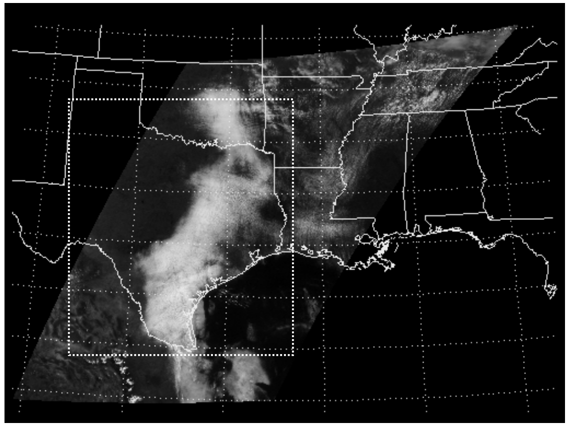


Key results

PBL mixing enhanced in adjustment to the observations

Influence of horizontal advection is negligible

3h forecast after assimilation

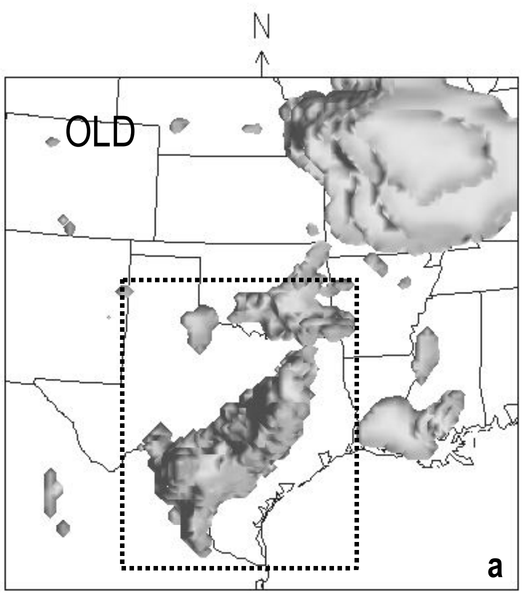


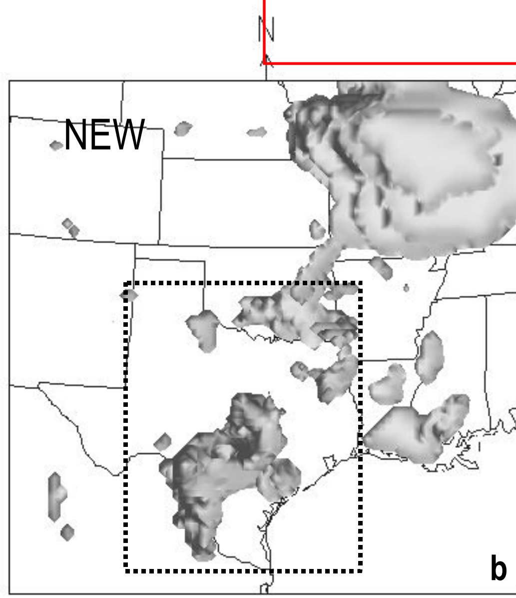
Key results

New forecast slightly better where cloud cover is correct

(-0.5 vs 0.1 K Tb error)

Neither forecast captures fast dissipation in south-west Texas due to the LBC error





CONCLUSIONS

- Measurable positive impact of VIS and IR measurements
- Plausible thermodynamic response
- Sensitivity of the cost function in model clear columns is negligible, <u>as expected</u>
- Strongly suggested need to incorporate other remote sensing or in situ measurements on mesoscales to further improve analysis of the cloud environment
- Demonstrated success with ‘cold start’ assimilation and relatively crude grid resolution encourages further research toward cycled and higher resolution cloud 4DDA

Extra slides

Cloud comparison

Information Content

	1500 UTC	2100 UTC

Ch 1

Visible optical depth

Ch 2

Cloud particle size

Ch 3

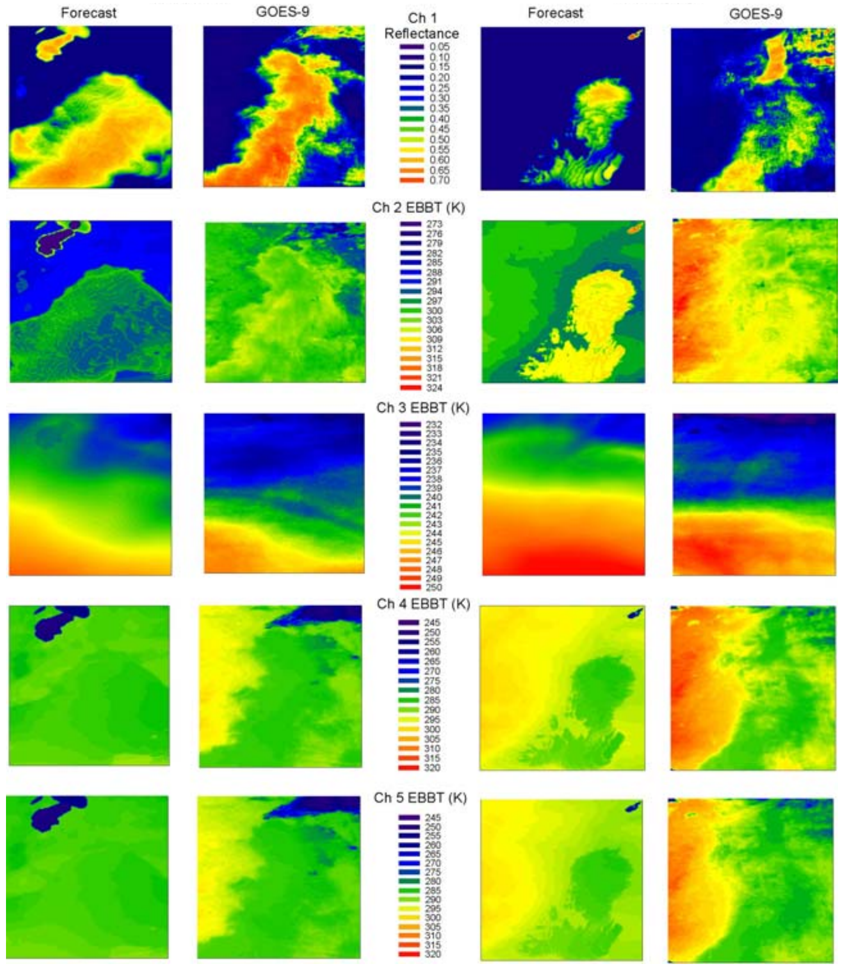
Upper trop humidity

Ch 4

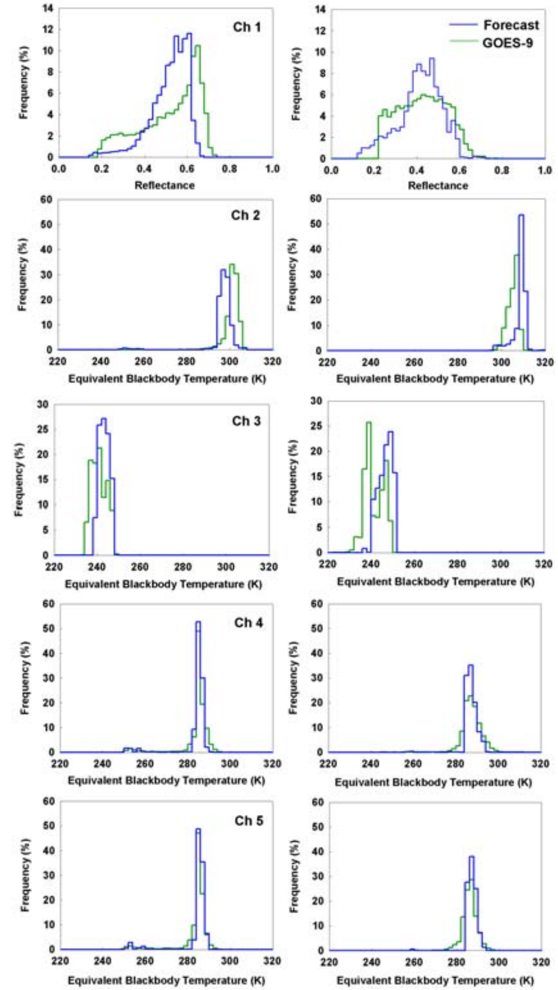
Cloud top temp

Ch 5

Cloud top temp; BL humidity



1500 UTC 2100 UTC



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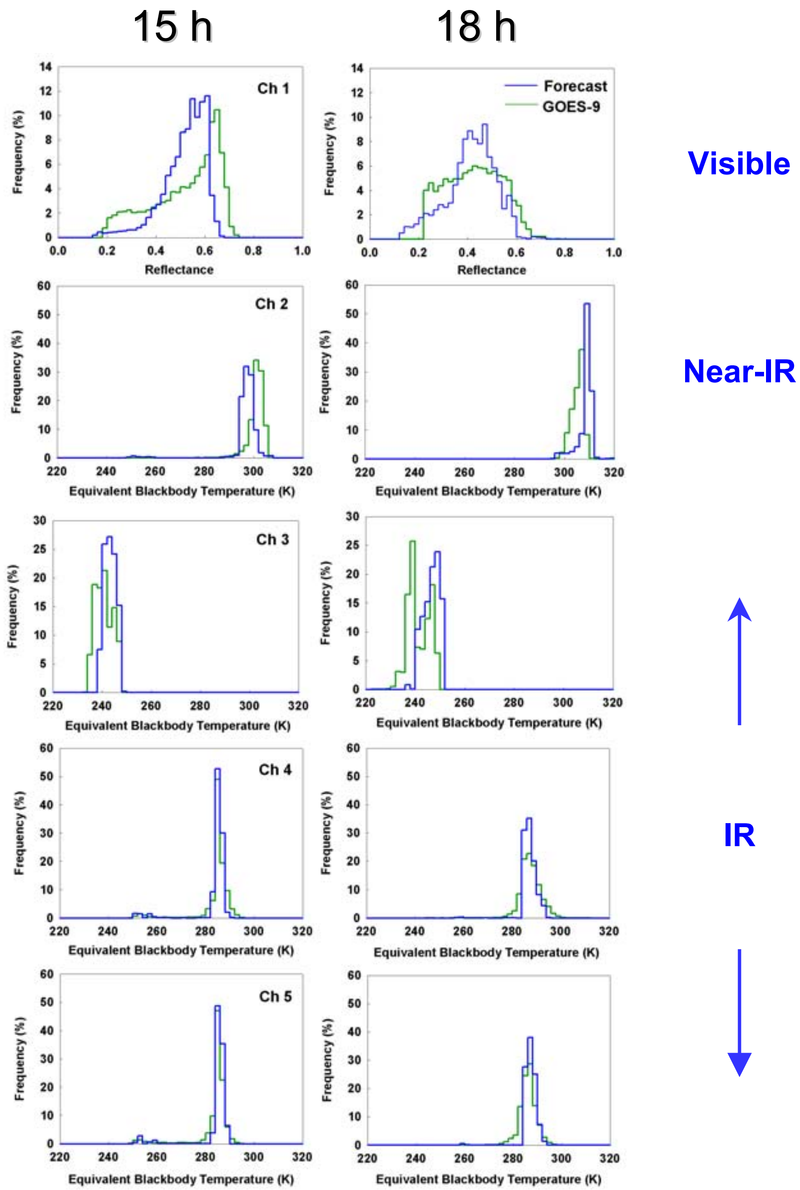
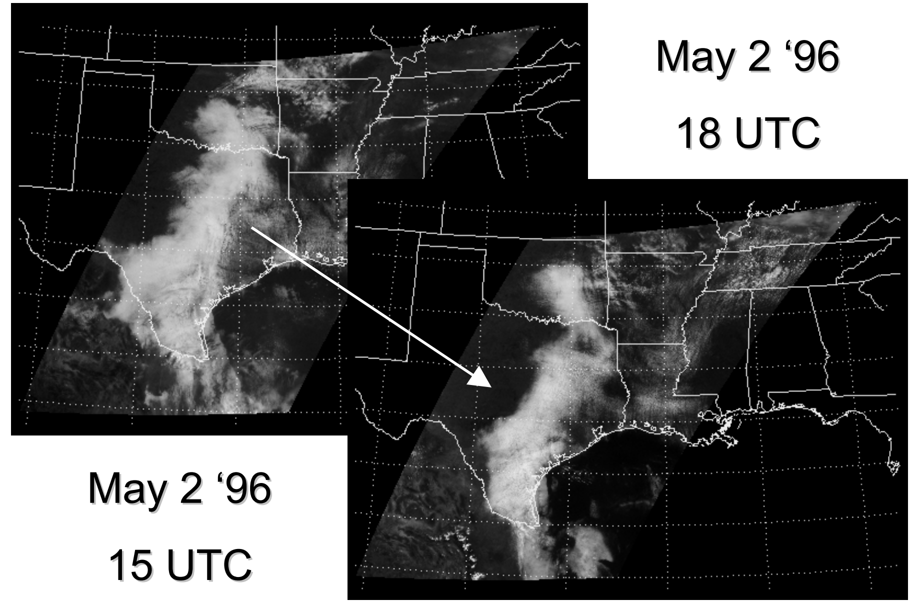
Cloud forecast verification in GOES imager space

warm continental stratus





Key result

Simulated cloudy radiances capture observed temporal/spatial changes

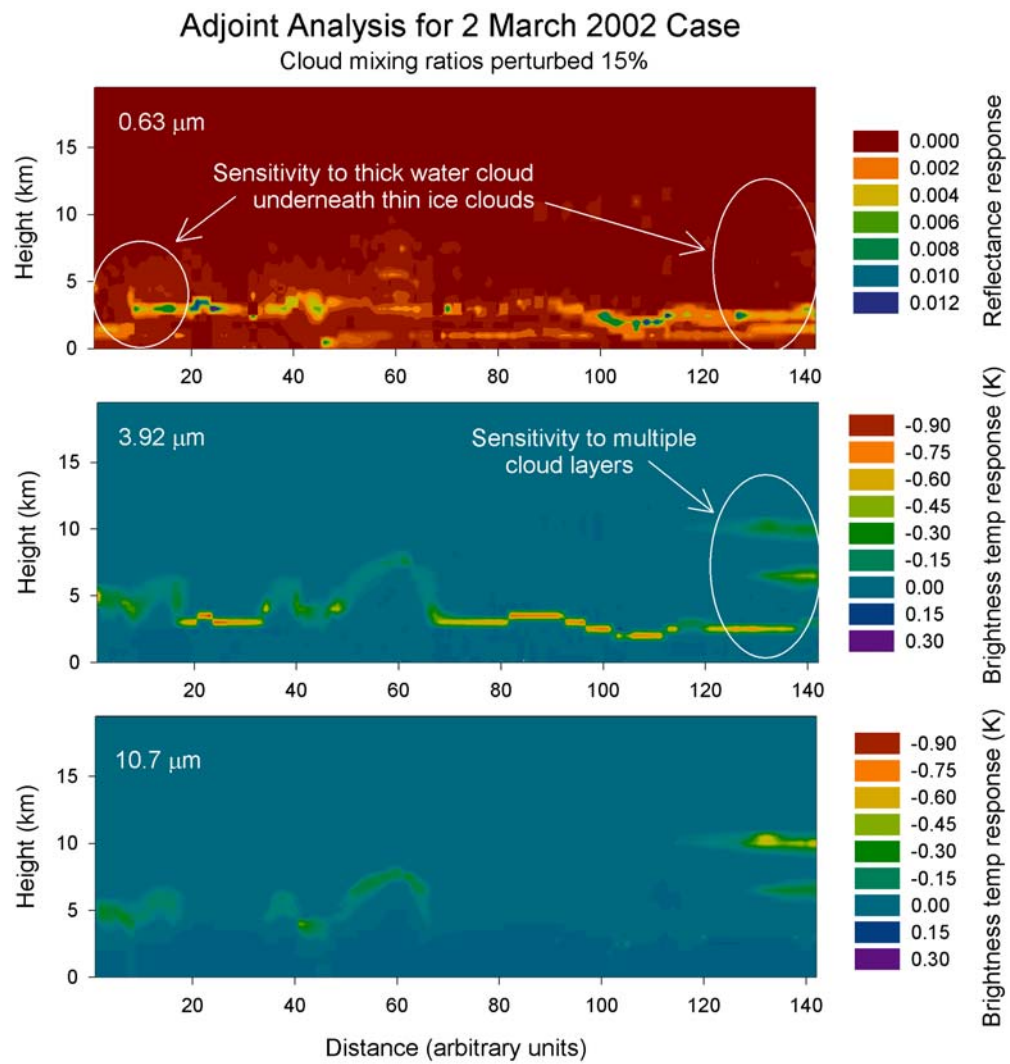
VIS and IR information content analysis continued
Mesoscale convective system case

Visible

Near IR

IR

Sensitivity to multiple cloud layers



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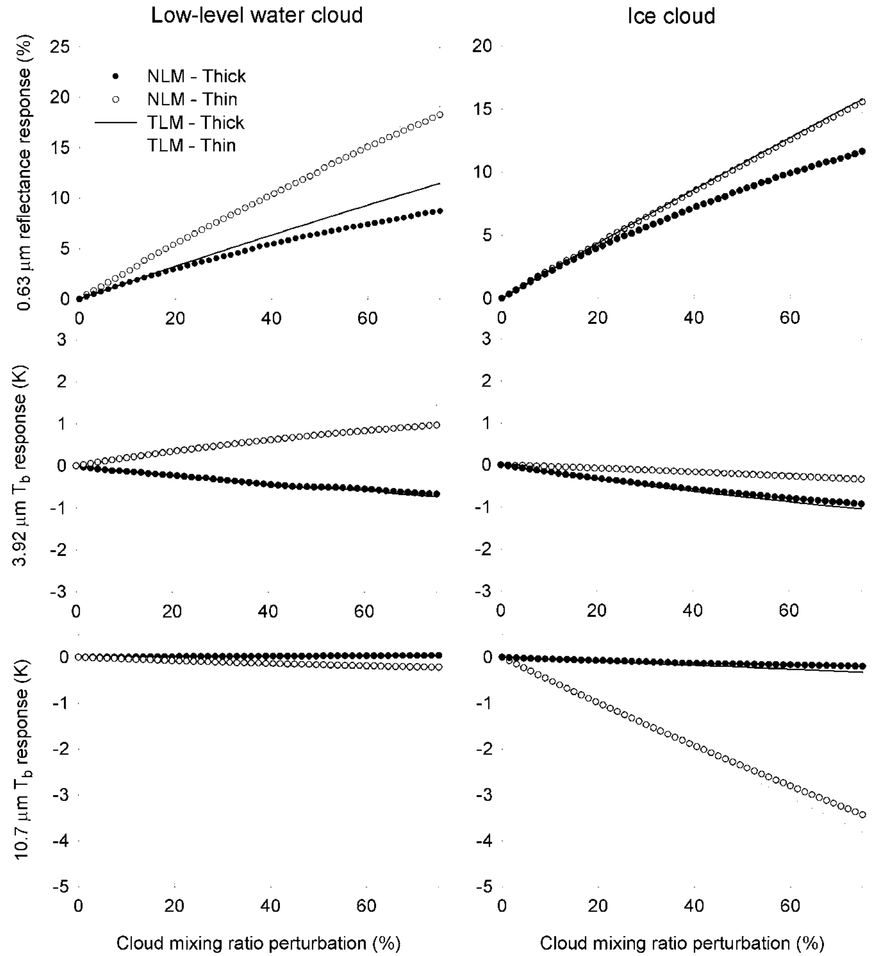
VIS and IR Satellite Observational Operator
Linearity test



Key result

VIS and IR OO is quasi linear for

wide range of cloud mixing ration perturbations

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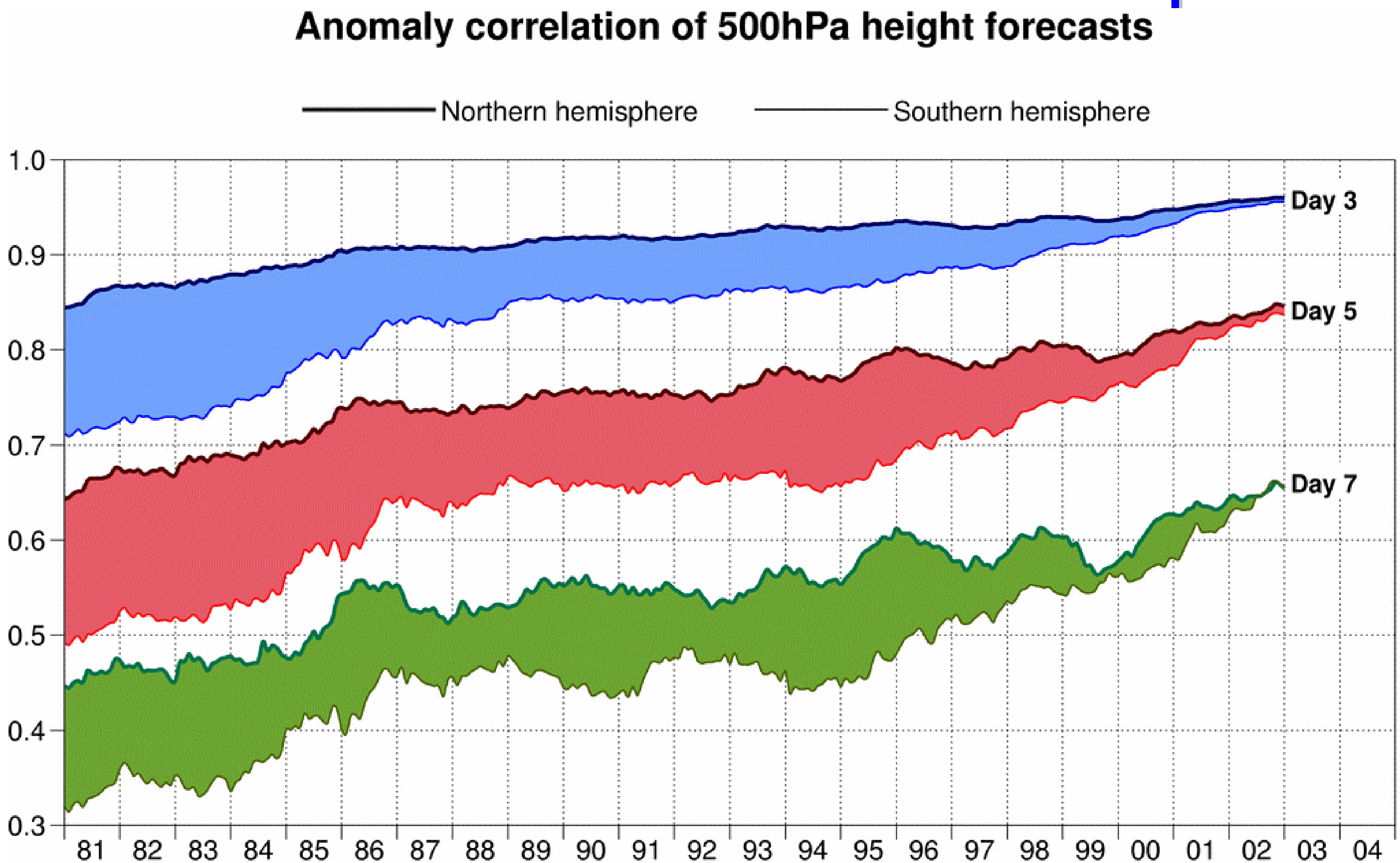
Evolution of forecast skill for northern and southern hemispheres



From Miller/ECMWF

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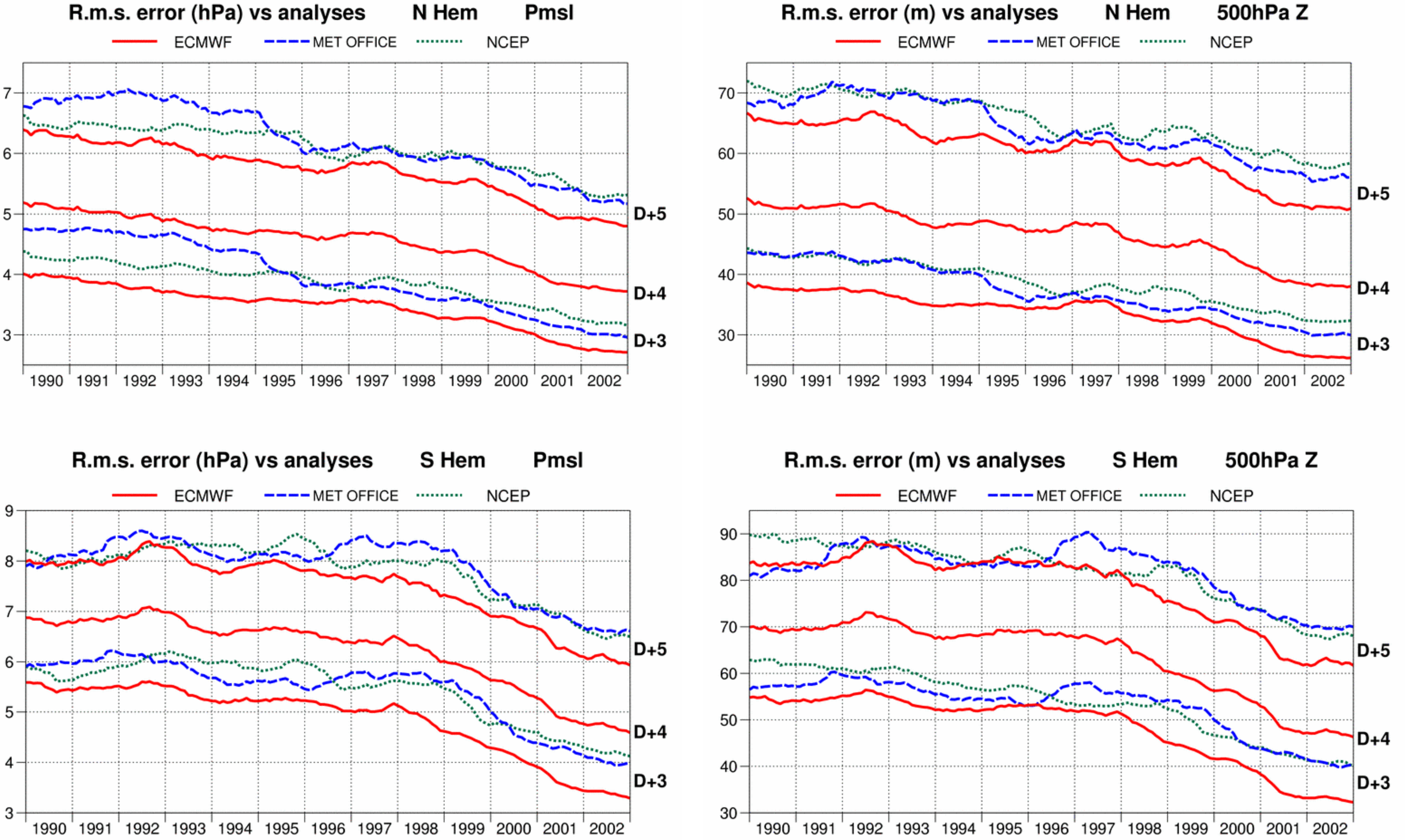
Annual-mean r.m.s. errors against analyses from WMO scores



From Miller/ECMWF

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Satellite Instruments and their Information Content

			Wavelength			Primary Information Content				
	Platform	Instrument	Visible	IR	Microwave	Temperature	Humidity	Cloud	Precipitation	Surface
Current	DMSP	SSM/I			√		●	●	●	●
		SSM/T			√	●			●	
		SSM/T-2			√		●		●	
		OLS	√	√				●		●
	NOAA	AMSU-A			√	●	●	●	●	●
		AMSU-B			√		●		●	
		HIRS/3		√		●	●	●		●
		AVHRR	√	√				●		●
	GOES	Imager	√	√			●	●		●
		Sounder	√	√		●	●	●		●
	Meteosat	Imager	√	√			●	●		●
	GMS	Imager	√	√			●	●		●
	Terra	MODIS	√	√		●	●	●		●
	TRMM	TMI			√		●	●	●	●
		VIRS	√	√				●		●
		PR			√				●	
	QuikSCAT	Scatterometer			√					●
Near-future	Aqua	AMSR-E			√		●	●	●	●
		AMSU			√	●	●	●	●	●
		HSB			√		●		●	
		AIRS		√		●	●	●		●
		MODIS	√	√		●	●	●		●
	ADEOS-II	AMSR			√		●	●	●	●
		GLI	√	√		●	●	●		●
		SeaWinds			√					●
	DMSP	SSMIS			√	●	●	●	●	●
		OLS	√	√				●		●
	Windsat	Polarimetric radiometer			√					●